Demonstration of Electrical Dispersion Compensation of Single Sideband Optical Transmission

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Abstract: We describe a demonstration of electrical chromatic dispersion compensation of 10 Gb/s single sideband optical signals. Eye-opening and bit error rates of less than 10^{-10} were achieved after compensation of -2040 ps/nm, equivalent to 120km of non-dispersion-shifted fibre and beyond the dispersion limit for 10Gb/s. A passive sideband filter was used to produce the single sideband signal, a technique that is applicable to low cost systems which use direct or electro-absorptive laser modulation. The wavelength tolerance of such systems was measured for the first time.

1 Introduction

Chromatic dispersion in optical fibre communication systems is caused by the variation of group velocity with wavelength leading to pulse spreading, in turn causing horizontal eye closure and a power penalty. As the range and bit rate of ethernet and metro systems is increased, there is a requirement for variable, high performance and inexpensive dispersion compensators that can be integrated with receiver circuitry.

Several methods of variable dispersion compensation in the optical domain have been proposed and demonstrated. These, in general, suffer from using expensive, lossy and bulky optical components that are unsuitable for low cost networks. Electrical filtering is easier and cheaper to implement. However, in the electrical domain, after direct detection of a conventional double side-band (DSB) signal, the phase information of the optical signal is lost. Therefore linear filtering can only provide limited compensation in this case. If only a single sideband is transmitted however, phase information is preserved and a filter with a linear group delay response can be used to correct accurately for the effects of dispersion [1]. This technique has the potential to be low cost, requiring only minor changes to existing direct detection optical communications systems.

Using single sideband (SSB) transmission and direct detection, compensation of 320km of NDSF fibre at 10Gb/s using a 30cm microstrip line has been reported [1]. The SSB signal was directly generated using a 2-electrode Mach-Zehnder modulator by applying a combination of the baseband signal and its Hilbert transform. This produces a high quality SSB signal in which the unwanted side band is suppressed by 20dB. However, low cost networks do not generally employ Mach-Zehnder modulators. Production of SSB signals using a passive optical filter to remove the majority of one side band has also been reported [2, 3]. Compensation using a coaxial cable and an analog transversal filter has been used to transmit over 225km of NDSF at 10Gb/s.

This paper describes a demonstration in which a microstrip filter is used to compensate for single side-band (SSB) optical signals. The SSB signal is generated using the passive filter approach and is therefore more relevant to low cost networks such as metro SDH and Ethernet.

2. System Description

The experimental arrangement used in the demonstration is shown in Figure 1. The optical signal was generated using a tuneable CW laser source with a linewidth of 700kHz, modulated by a Mach-Zehnder modulator with a 10Gb/s pseudo-random binary sequence.

The unwanted sideband was suppressed using one channel of a commercially available passive spectral slicer with a 3dB bandwidth of 0.34nm. Figure 2 shows the measured characteristics of the filter. By choosing the laser wavelength, either upper or lower side-bands can be suppressed, allowing microstrip compensation of either anomalous or normal chromatic dispersion respectively. Figure 3 shows a simulated optical spectrum using the measured filter data with a laser wavelength of 1546.23nm, which was found to be the optimum wavelength for final eye quality.

The signal was then distorted by dispersion achieved using lengths of dispersion compensating fibre (DCF) giving up to –2380ps/nm of total dispersion, an absolute value equivalent to the dispersion of 140km of non-dispersion shifted fibre (NDSF). Optical amplification was required before the side-band filter and after the DCF.

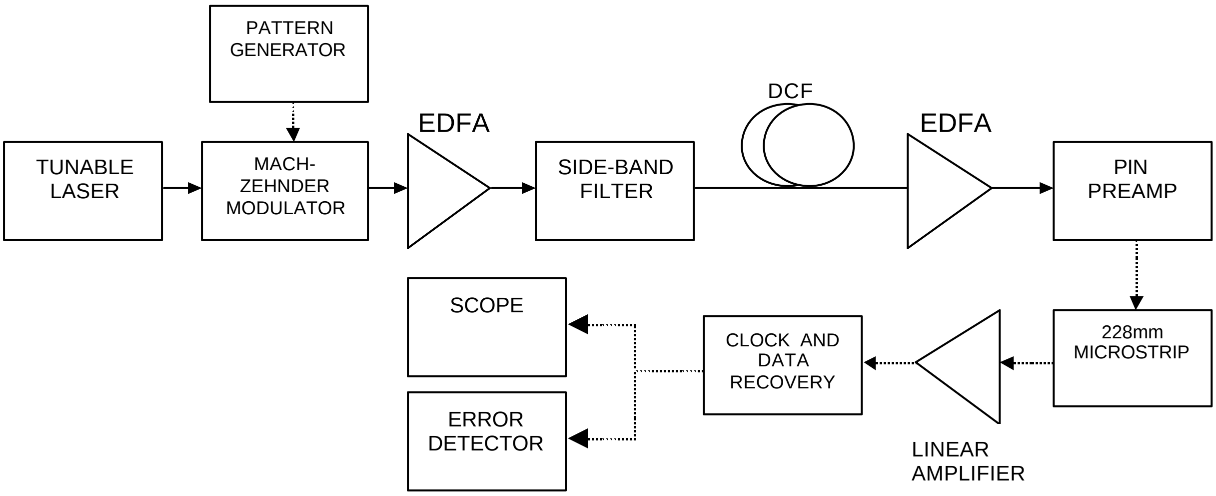


Figure 1: Experimental setup

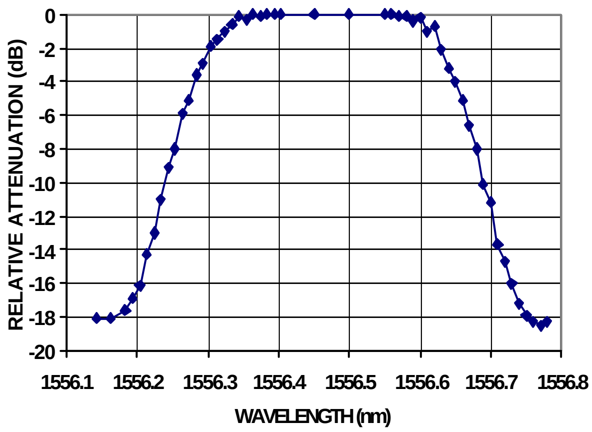


Figure 2: Transmission characteristics of the spectral slicer

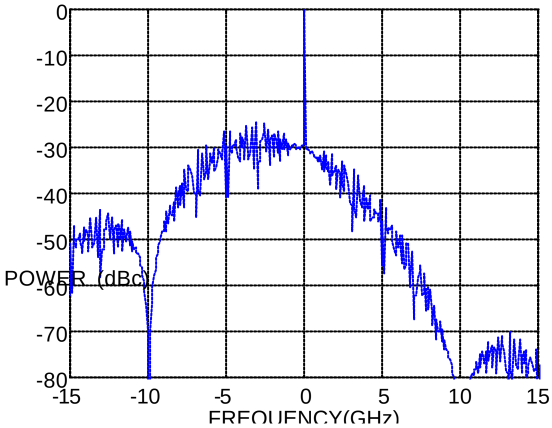
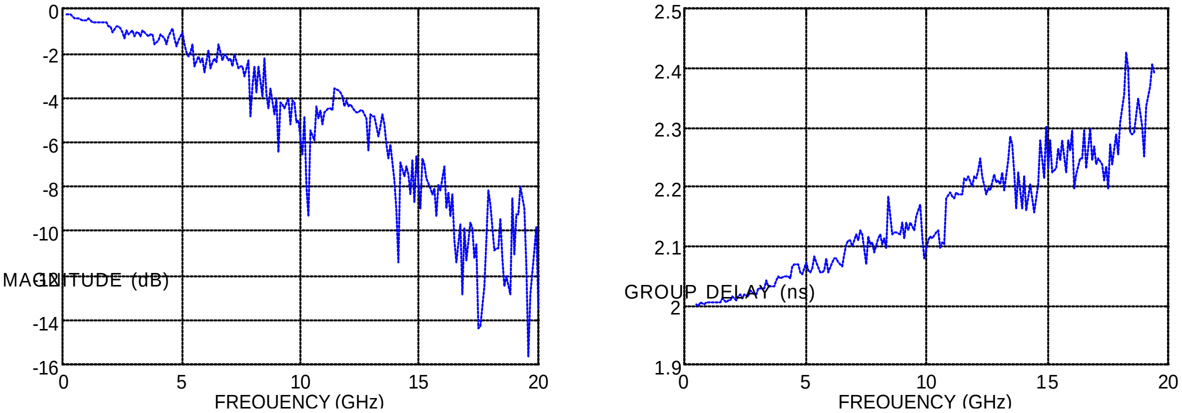


Figure 3: Simulated optical power spectrum after transmission through spectral slicer (using measured filter transmission characteristic)

After detection, ideally, an electrical compensator is required with an all-pass amplitude response and a linear group delay response over the signal bandwidth. There are many ways of producing such a filter, the simplest being a length of microstrip. The compensator used in this demonstration was a connectorised microstrip line, 228mm in length, implemented on a RT/Duroid 6010LM substrate (e_r = 10.2). The microstrip dimensions were optimised to give characteristic impedance of 50Ω and a linear dispersion characteristic from DC to over 20GHz. The measured attenuation and delay characteristics of the compensator are shown in Figure 4. The compensator is optimised for correcting ±2040 ps/nm of fibre dispersion. As normal dispersion fibre was used with a positive dispersion compensator, the upper sideband (in wavelength) must be transmitted in this case.



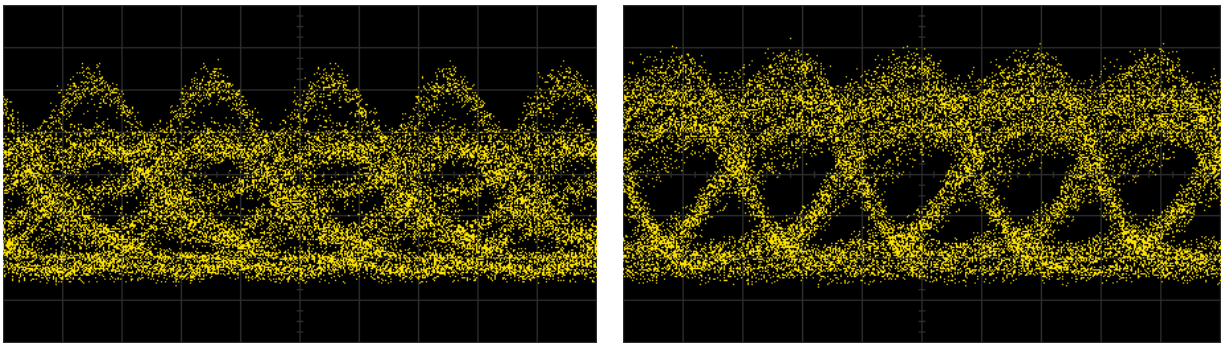
(a) (b)

Figure 4: Measured S-parameters of the 228mm microstrip line (a) magnitude (b) group delay

3. Results

After compensation with the 228mm microstrip, eye opening could be achieved for NDSF equivalent lengths of up to 140km. An example is shown in Figure 5 at the optimum laser wavelength.

In low cost networks, the required accuracy of the laser wavelength is an important issue. To investigate the sensitivity of the system performance to the detuning of the laser and sideband filter, measurements of the bit error rate (BER) were made for a range of laser wavelengths relative to the filter (Figure 6). It can be seen that an error rate of less that 10^{-10} is achieved over a range of 0.01nm. If temperature tuning of a DFB laser is used in the transmitter, this would require a temperature set point accuracy of 0.1K (assuming a typical temperature coefficient for a DFB laser to be 0.09 nm/K [4]). For 40 Gb/s systems, in which the tolerance would be relaxed by a factor of 4, the required set point accuracy is 0.4K. For comparison, the wavelengths of DFB lasers used for WDM applications have to be controlled to within 10% of the channel spacing [5]. This is 0.04nm for the 50GHz grid, giving a temperature set point accuracy of 0.45K.



(a) (b)

Figure 5: Eye diagrams (a) before and (b) after compensation of –2380ps/nm of fibre dispersion, using the 228mm microstrip line

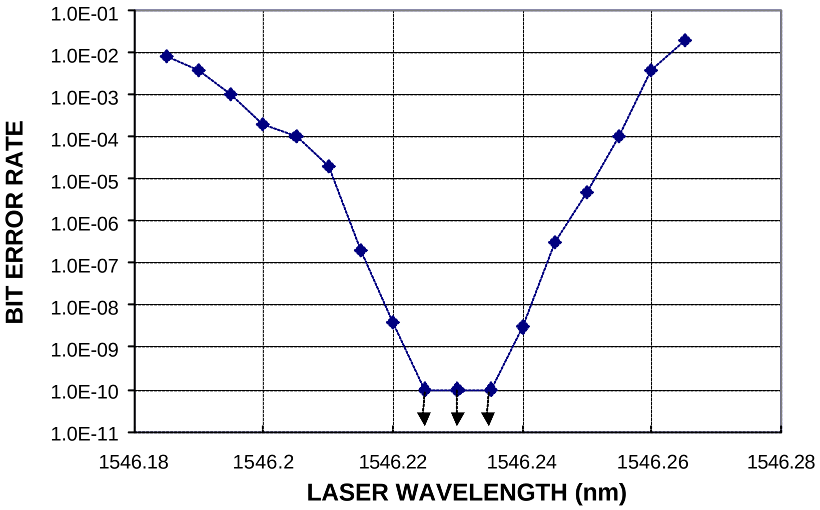


Figure 6: Sensitivity of bit error rate to laser wavelength with fixed sideband filter and compensation of –2040ps/nm

4. Conclusions

We demonstrated electrical chromatic dispersion compensation of 10 Gb/s single sideband optical signals. Eye-opening and bit error rates of less than 10^{-10} were obtained after transmission through dispersion of -2040 ps/nm, an absolute value equivalent to 120km of NDSF equivalent fibre, which is beyond the dispersion limit for 10Gb/s.

A Mach-Zehnder modulator and a passive optical filter were used to generate the single sideband signals. The technique is therefore applicable to low cost systems which use direct or electro-absorptive laser modulation. The wavelength tolerance of such systems was measured for the first time and showed error-free operation over a wavelength range of 0.01nm, corresponding to temperature control of a DFB laser of 0.1K. This is achievable in practice, although is more stringent than the requirement for WDM laser control. At 40 Gb/s, the temperature control would be relaxed to 0.4K, similar to that required in 50 GHz spaced WDM systems.

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References

[1] Sieben, Conradi and Dods, ‘Optical single sideband transmission at 10Gb/s using only electrical dispersion compensation’, Journal of Lightwave Technology, vol 17 (10), pp. 1742-1749, Oct 1999

[2] Kim and Gnauck, ‘10Gb/s 177km transmission over conventional singlemode fibre using a vestigial sideband modulation format’, Electronics Letters, vol 37 (25), pp. 1533-1534, Dec 2001

[3] Bulow, Buchali, Nicolas, ‘Dispersion mitigation using a fiber-Bragg-grating sideband filter and a tunable electronic equalizer’, Proc. Optical Fiber Communication Conference, OFC 2001, vol.3, paper WDD34, Anaheim, CA, USA

[4] Bookham Technology, LC131-98 10Gb/s uncooled DFB laser datasheet

[5] ITU-T-G.692 Specification, ‘Optical interfaces for multichannel systems with optical amplifiers’